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Discussion of Synchronization Words

J.C. Morakis

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J. C. Morakis   NASA/GSFC

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Introduction

In choosing a 32-bit PCM synchronization pattern, or sequence, for the CCSDS
Packet Telemetry and Telemetry Channel Coding Recommendations the following
constraints were applied:

1. NASA makes frequent use of PSK (suppressed carrier) modulation for both
telemetry and command transmissions. Such transmissions are subject to
polarity ambiguity. Also, tape-recorded telemetry is frequently played back
in reverse to avoid the complication and inefficiency of rewinding the tape
recorder before a data dump. Therefore, the probability of false
synchronization (i.e., "false alarm" or Type II error) should be minimal when
the synchronization sequence is autocorrelated with itself, its complement,
its reverse (mirror image), and its reverse complement, over the range of the
prevailing channel signal-to-noise ratios.

2. Since two distinct modes of synchronization operation involving synching
for frames or code block will be used, the condition in (1) should also be met
for the case of cross-correlation of this synchronization sequence with one
other synchronization sequence.

3. The probability of synchronization failure (i.e., "false rejection" or
Type I error) should also be kept reasonably low. This was done by allowing
up to two bit errors in a "correct" synchronization word. It was assumed that
it was not necessary to make any other allowance for Type I errors. In a
practical case, additional considerations like run lengths or balance of 1's
and 0's might enter into selecting a synchronization word.

Rationale:

According to the CCSDS Packet Telemetry Recommendation, a unique synchroniza-
tion sequence is needed for either the R/S code block or for the transport
frame synchronization if R/S block synchronization is not used. It is assumed
that the ground system does not know in advance which situation exists. In
addition to performing the synchronization function, these codes must not be
mistaken for one another.

The original 32-bit synchronization codes tested were obtained from a variety
of sources: existing telemetry standards, published and unpublished papers, a
new exhaustive search, etc. Therefore they represent a good sampling from a
very large number of possible choices.

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Procedure:

Case 1: Autocorrelation

In this case the incoming synchronization sequence is "compared" to four synchronization "recognizers" containing respectively: the synchronization sequence, its complement, its reverse, and the reverse complement.

The incoming sequence is allowed to enter all four recognizers simultaneously in serial steps one bit at a time, and the correlation for each recognizer is evaluated for each step. There are 63 such serial steps for which there is some degree of overlap between the incoming synchronization word and the recognizers, 62 of which represent incorrect synchronization positions and one of which is the correct synchronization position. In the non-overlap region the bits are considered to be random with a probability of agreement equal to 0.5 . The probability of false synchronization over the incorrect synchronization positions was calculated for each recognizer allowing up to a total of two errors in the incoming 32-bit synchronization word, and the probabilities of false synchronization for each recognizer were added.*

To produce a false agreement in the overlap regions the disagreeing bits of the incoming sequence must be changed with a probability p, and the agreeing bits must remain the same with a probability 1-p (p is the channel bit error probability).

Thus the probability of false synchronization is the sum of the above (4 X 63-1) probabilities; i.e., the probability for all steps except the one where the recognizer is the same as the synchronization sequence <u>and</u> the shift number is 32 (all agreements in this recognizer except for <u>up</u> to 2 bit errors)*.

The probability p was allowed to take on values of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-5}, and correct synchronization was declared when at least 30 out of 32 bits were in agreement.

The above procedure was repeated for each candidate sequence for each of the 32 ring (cyclic) permutations of that sequence and the permutation with the minimum probability of false synchronization was selected. Based on the above, a set of candidate codes having relatively good performance was selected. The nine sequences tested are shown in Table 1 and the probabilities of false synchronization for the best rotation are shown in Table 2, assuming channel bit error probabilities of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-5} respectively.

Note: The "false synchronization" probabilities calculated here apply to the 63 steps where the synchronization word is passing through the recognizers. The actual system operational false synchronization probability would depend on a number of additional factors such as frame or block length, acquisition

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* In the actual calculation, I adopted shortcuts based on the very small probabilities involved; see Appendix A.

and lock strategies, redundancies in the data, etc. These considerations are
system peculiar and are outside the scope of this paper. The term "false
synchronization" is retained to simplify the explanation; the numerical values
of "false synchronization" probability calculated below are sufficient
to rank the desirability of the candidate words but do not represent a
calculation of actual false synchronization probability in any particular
system.

Case 2: Cross-correlation

The false synchronization probability was calculated for each pair of the
above sequences (cross-correlation) in the manner described in Case 1 except
for the ring permutation part; in Case 2, the pair with minimum false
synchronization probability (i.e., cross-correlation) was selected. In other
words, it was assumed that between the synchronization words that had already
shown good performance individually the probability of false cross-correlation
would be the most important source of error.

For the cross-correlation case pairs of sequences from Table 1 with the lowest
probability of false synchronization under the same channel bit error
probability assumptions are shown in Table 3. The program for this calculation
is found in Appendix B.

Case 3. Performance of Convolutionally Encoded Synch Sequences

Sequences 9 & 4 of Table 1 were convolutionally encoded with parity bit
inverted according to the CCSDS Recommendation and tested for auto-correlation
as in Case 1 assuming no flush pattern (i.e., with 52 effective
synchronization bits). The false synchronization probabilities were about 5
orders of magnitude lower than those of the uncoded case (9 orders of
magnitude less for the 64-bit case with flush pattern). Sequence 4 & 9 have
also been tested for cross-correlation and the probabilities of false
synchronization were found to be: for 52-bit cross-correlation about 5 orders
of magnitude less than for 52-bit auto-correlation, and for 64-bit
cross-correlation about 9 orders of magnitude less than for the 64-bit
auto-correlation. Consequently we do not anticipate any problems if some
users choose to employ Viterbi-encoded synchronization. The program in
Appendix C was used to calculate the false sync. probabilities for these
encoded sync. sequences.

Conclusion:

1. Recommendation

The recommended standard marker pattern is sequence #9 in Table 1, for the
initial synchronization process (the R-S codeblock, or, in systems not using
R-S coding, the Telemetry Transfer Frame). This pattern may be represented in
hexadecimal notation as:

<p style="text-align:center">1 A C F F C 1 D</p>

In the event it is necessary to handle a second marker imbedded within the above stream, sequence #4 in Table 1 is recommended as the imbedded marker. This latter pattern may be represented in hexadecimal notation as:

$$B\ 3\ 8\ 3\ 5\ 2\ 2\ F$$

2. Rationale for Recommendation

Sequence #9 is recommended as the first synchronization pattern because of its superior performance at the 3 lower error rates.

At first glance, it might appear that sequence #6 should be the second choice. However, if #6 were chosen as the second synchronization sequence, the auto-correlation probability would be 0.33×10^{-4} and the cross-correlation 0.07×10^{-4}.

On the other hand if #4 is chosen the auto-correlation will be 0.19×10^{-4} and the cross-correlation 0.13×10^{-4}. Since both latter probabilities are comparable to that of the auto-correlation of #9 we recommend #4 as the second sequence.

Overall synchronization performance is characterized by a function involving the sum of the probabilities involved, examination of Tables 2 and 3 shows that the penalty of choosing #6 is too high and the benefit is relatively insignificant.

TABLE 1
LIST OF 32-BIT SYNCHRONIZATION SEQUENCES

SEQUENCE #1	01	100	010	000	100	001	111	111	111	001	101
SEQUENCE #2	01	110	100	110	100	001	000	000	111	111	001
SEQUENCE #3	01	100	000	101	101	010	001	110	111	110	010
SEQUENCE #4	10	110	011	100	000	110	101	001	000	101	111
SEQUENCE #5	10	100	100	000	101	011	101	100	011	111	001
SEQUENCE #6	00	110	101	001	011	101	111	100	001	010	011
SEQUENCE #7	00	010	100	110	101	100	111	111	100	000	010
SEQUENCE #8	00	111	111	010	001	000	010	100	101	110	010
SEQUENCE #9	00	011	010	110	011	111	111	110	000	011	101

TABLE 2
PROBABILITY OF FALSE SYNCH-WINDOW ACCEPTANCE WITH ONE SYNCH. WORD
(AUTOCORRELATION)

CHANNEL BIT ERROR PROBABILITY 10^{-1}	10^{-2}	10^{-3}	10^{-5}
SEQUENCE NO.			
#1 $\quad 0.13 \times 10^{-4}$	0.05×10^{-4}	0.05×10^{-4}	0.05×10^{-4}
#2 $\quad 0.12 \times 10^{-4}$	0.08×10^{-4}	0.07×10^{-4}	0.07×10^{-4}
#3 $\quad 0.16 \times 10^{-4}$	0.05×10^{-4}	0.05×10^{-4}	0.05×10^{-4}
#4 $\quad 0.11 \times 10^{-4}$	0.05×10^{-4}	0.05×10^{-4}	0.05×10^{-4}
#5 $\quad 0.03 \times 10^{-4}$	0.07×10^{-4}	0.06×10^{-4}	0.06×10^{-4}
#6 $\quad 0.13 \times 10^{-4}$	0.08×10^{-4}	0.08×10^{-4}	0.09×10^{-4}
#7 $\quad 0.25 \times 10^{-4}$	0.09×10^{-4}	0.09×10^{-4}	0.09×10^{-4}
#8 $\quad 0.16 \times 10^{-4}$	0.05×10^{-4}	0.05×10^{-4}	0.04×10^{-4}
#9 $\quad 0.16 \times 10^{-4}$	0.04×10^{-4}	0.03×10^{-4}	0.03×10^{-4}

TABLE 3
PROBABILITY OF FALSE SYNCH-WINDOW ACCEPTANCE WITH TWO SYNCH. WORDS
(CROSS-CORRELATION)

CHANNEL BIT ERROR PROBABILITY 10^{-1}	10^{-2}	10^{-3}	10^{-5}
SEQUENCE PAIRS			
#1, #4 $\quad 0.05 \times 10^{-4}$	0.03×10^{-4}	0.03×10^{-4}	0.03×10^{-4}
#1, #7 $\quad 0.05 \times 10^{-4}$	0.03×10^{-4}	0.03×10^{-4}	0.03×10^{-4}
#6, #9 $\quad 0.10 \times 10^{-4}$	0.02×10^{-4}	0.02×10^{-4}	0.02×10^{-4}
#4, #9 $\quad 0.07 \times 10^{-4}$	0.04×10^{-4}	0.03×10^{-4}	0.03×10^{-4}

AUTOCORRELATION SYNC

The following DEC BASIC program was used to calculate the entries in Table 2.

```
SET NO DOUBLE
10 KK=32
20 PRINT 'AUTOCORRELLATION OF SYNC SEQUENCES';KK;'BITS',DATE$(0%)
30 DIM S(9,64),CC(64),CR(64)
40 DECLARE DOUBLE P11(32),P22(32)
50 OPEN 'lp:' FOR OUTPUT AS FILE #2
60 PRINT 'enter 4 probabilities of error'
70 INPUT P,PP,PPP,PPPP
80 PRINT 'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
90 PRINT #2,'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
100 Q=1-P\QQ=1-PP\QQQ=1-PPP
110 QQQQ=1-PPPP
120 LP=LOG10(P)
130 LPP=LOG10(PP)
140 LPPP=LOG10(PPP)
150 LQ=LOG10(Q)
160 LQQ=LOG10(QQ)
170 LQQQ=LOG10(QQQ)
180 L5=LOG10(.5)
190 PRINT #2,'AUTOCORRELLATION OF SYNC SEQUENCES';KK;'BITS',DATE$(0%)
200 LQQQQ=LOG10(QQQQ)
210 LPPPP=LOG10(PPPP)
220 DATA 2,3,2,6,1,0,2,0,7,7,7
230 DATA 2,2,7,2,3,2,0,4,0,3,7
240 DATA 0,1,3,2,4,3,5,7,4,4,6
250 DATA 1,2,2,1,3,7,3,1,6,0,3
260 DATA 2,3,2,2,0,2,5,6,6,1,7
270 DATA 1,2,2,7,3,7,0,2,4,6,3
280 DATA 3,7,4,0,2,0,5,1,5,3,1
290 DATA 3,1,0,7,7,2,1,0,2,4,5
295 DATA 3,7,7,4,0,7,2,1,5,3,1
300 RESTORE 220
310 KK2=KK*2
320 FOR I=1 TO 9
330 PRINT 'SEQUENCE #';I
340 PRINT #2,'SEQUENCE #';I
350 PRINT 'S       ';
360 PRINT #2,'S       ';
370 FOR JJ=0 TO 10
```

```
380 READ L
390 IF JJ=6 THEN PRINT #2,
400 FOR J=0 TO 2
410 IF JJ=0 AND J=0 THEN 470
420 K=3*JJ+J
430 EX=2^(2-J)
440 S(I,K)=(L AND EX)/EX
450 PRINT S(I,K);
460 PRINT #2,S(I,K);
470 NEXT J
480 PRINT #2,'  ';
490 PRINT '  ';
500 MIN=-100
510 NEXT JJ
520 PRINT
530 PRINT #2,
540 S(I,0)=S(I,K)
550 NEXT I
560 FOR II=1 TO 9
570 MVAR1=100
580 MVAR=100
590 MDIFF1=KK/2
600 MDIFF=KK/2
601 MDIFF3=KK/2
602 MDIFF5=KK/2
603 MDIFF7=KK/2
610 FOR L=0 TO KK-1
620 IF L=0 THEN 750
630 PRINT 'S      ';
640 PRINT #2,'S      ';
650 FOR III=0 TO KK-1
660 S(II,III)=S(II,III+1)
670 IF III=0 THEN 710
680 IF III=24 THEN PRINT #2,
690 PRINT #2,S(II,III);
700 PRINT S(II,III);
710 NEXT III
720 S(II,KK)=S(II,0)
730 PRINT #2,S(II,KK)
740 PRINT S(II,KK)
750 PRINT 'S(Rev)';
760 PRINT #2,'S(Rev)';
770 FOR III=1 TO KK
780 IF III=24 THEN PRINT #2,
790 PRINT #2,S(II,KK+1-III);
800 PRINT S(II,KK+1-III);
810 NEXT III
820 PRINT #2,
830 PRINT
840 PRINT '# OF DISAGREEMENTS IN SEQUENCE';II;'ROTATION';L
850 AVE=0\VAR=0\BB=0
860 AVE1=0\VAR1=0\BA=0
870 PRINT #2,'# OF DISAGREEMENTS IN SEQUENCE';II;'ROTATION';L
880 MAX=0
```

```
890 MIN=-100
891 MIN3=-100
892 MIN5=-100
893 MIN7=-100
894 T1=0\T2=0
895 T3=0\T4=0
896 T5=0\T6=0
897 T7=0\T8=0
900 PRINT 'S,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
910 REM PRINT #2,'S,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
920 FOR I=1 TO 2*KK-1
930 SS=0
940 SSS=0
945 IF I>KK THEN 982
947 DELTA=I
950 FOR J=1 TO I
960 SS=SS+(S(II,KK-I+J) XOR S(II,J))
970 SSS=SSS+(S(II,KK-I+J) XOR S(II,KK+1-J))
980 NEXT J
981 GOTO 990
982 DELTA=2*KK-I
985 FOR J=I-KK+1 TO KK
986 SS=SS+(S(II,KK-I+J) XOR S(II,J))
987 SSS=SSS+(S(II,KK-I+J) XOR S(II,KK+1-J))
988 NEXT J
990 KISS=DELTA-SS
1000 KISSS=DELTA-SSS
1001 CR(I)=SSS
1002 CC(I)=SS
1005 DELBAR=KK-DELTA
1010 L5I=L5*DELBAR
1020 P1=LP*SS+LQ*KISS+L5I
1024 IF P1<-10 THEN 1078
1035 P3=LPP*SS+LQQ*KISS+L5I
1037 P5=LPPP*SS+LQQQ*KISS+L5I
1038 P7=LPPPP*SS+LQQQQ*KISS+L5I
1039 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1040 REM PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1041 IF I=KK THEN PRINT \ GOTO 1078
1042 IF SS>1 THEN 1055
1044 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1048 GOTO 1057
1055 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1057 IF P1>-15 THEN P1=F*10^P1 ELSE P1=0
1058 IF P3>-15 THEN P3=F*10^P3 ELSE P3=0
1059 IF P5>-15 THEN P5=F*10^P5 ELSE P5=0
1060 IF P7>-15 THEN P7=F*10^P7 ELSE P7=0
1070 PRINT TAB(30);P1;P3;P5;P7
1071 REM PRINT #2,TAB(31);P1;P3;P5;P7
1073 T1=T1+P1
1074 T3=T3+P3
1075 T5=T5+P5
1076 T7=T7+P7
1078 REM
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1090 P2=LP*SSS+LQ*KISSS+L5I
1100 IF P2<-1C THEN 1180
1105 P4=LPP*SSS+LQQ*KISSS+L5I
1110 P6=LPPP*SSS+LQQQ*KISSS+L5I
1120 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1130 REM PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1140 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1144 IF SSS>1 THEN 1150
1146 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1148 GOTO 1152
1150 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1152 IF P2>-15 THEN P2=F*10^P2 ELSE P2=0
1154 IF P4>-15 THEN P4=F*10^P4 ELSE P4=0
1156 IF P6>-15 THEN P6=F*10^P6 ELSE P6=0
1158 IF P8>-15 THEN P8=F*10^P8 ELSE P8=0
1160 PRINT TAB(30);P2;P4;P6;P8
1162 REM PRINT #2,TAB(31);P2;P4;P6;P8
1164 T2=T2+P2
1166 T4=T4+P4
1168 T6=T6+P6
1170 T8=T8+P8
1180 NEXT I
1185 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1186 PRINT #2,'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1190 FOR I=1 TO 2*KK-1
1191 IF I=20 OR I=40 THEN PRINT 'NORMAL'
1192 IF I=20 OR I=40 THEN PRINT #2,'NORMAL'
1193 PRINT CC(I);
1194 PRINT #2,CC(I);
1195 NEXT I
1196 PRINT 'N'
1197 PRINT #2,'N'
1198 FOR I=1 TO 2*KK-1
1199 IF I=20 OR I=40 THEN PRINT 'REVERSE'
1200 IF I=20 OR I=40 THEN PRINT #2,'REVERSE'
1201 PRINT CR(I);
1202 PRINT #2,CR(I);
1203 NEXT I
1204 PRINT 'R'
1205 PRINT #2,'R'
1231 PRINT #2,'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1232 PRINT 'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1235 PRINT 'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1236 PRINT #2,'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1249 PRINT 'COMPLEMENTS'
1250 PRINT #2,'COMPLEMENTS'
1255 TT1=0\TT2=0
1256 PRINT 'S,DEL,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
1258 REM PRINT #2,'S,DEL,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
1260 FOR I=1 TO 2*KK-1
1262 IF I>KK THEN 1268
1264 DELTA=I
1266 GOTO 1270
1268 DELTA=2*KK-I
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1270 SS=DELTA-CC(I)
1272 SSS=DELTA-CR(I)
1274 KISS=DELTA-SS
1276 KISSS=DELTA-SSS
1278 CR(I)=SSS
1280 CC(I)=SS
1282 DELBAR=KK-DELTA
1284 L5I=L5*DELBAR
1286 P1=LP*SS+LQ*KISS+L5I
1288 IF P1<-10 THEN 1328
1290 P3=LPP*SS+LQQ*KISS+L5I
1292 P5=LPPP*SS+LQQQ*KISS+L5I
1294 P7=LPPPP*SS+LQQQQ*KISS+L5I
1296 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1298 REM PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1300 IF SS>1 THEN 1306
1302 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1304 GOTO 108
1306 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1308 IF 1-5 HE P1=*1^P1 ELP=0
1310 IF P3>-15 THEN P3=F*10^P3 ELSE P3=0
1312 IF P5>-15 THEN P5=F*10^P5 ELSE P5=014 IF P7>-15 THEN P7=F*10^P7 ELSE P7=0
1316 PRINT TAB(30);P1;P3;P5;P7
1318 REM PRINT #2,TAB(31);P1;P3;P5;P7
1320 T1=T1+P1
1321 TT1=TT1+P1
1322 T3=T3+P3
1324 T5=T5+P5
1326 T7=T7+P7
1328 REM
1330 P2=LP*SSS+LQ*KISSS+L5I
1332 IF P2<-10 THEN 1372
1334 P4=LPP*SSS+LQQ*KISSS+L5I
1336 P6=LPPP*SSS+LQQQ*KISSS+L5I
1338 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1340 REM PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1342 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1344 IF SSS>1 THEN 1350
1346 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1348 GOTO 1352
1350 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1352 IF P2>-15 THEN P2=F*10^P2 ELSE P2=0
1354 IF P4>-15 THEN P4=F*10^P4 ELSE P4=0
1356 IF P6>-15 THEN P6=F*10^P6 ELSE P6=0
1358 IF P8>-15 THEN P8=F*10^P8 ELSE P8=0
1360 PRINT TAB(30);P2;P4;P6;P8
1362 REM PRINT #2,TAB(31);P2;P4;P6;P8
1363 T2=T2+P2
1364 TT2=TT2+P2
1366 T4=T4+P4
1368 T6=T6+P6
1370 T8=T8+P8
1372 NEXT I
1374 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
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1376 PRINT #2,'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1378 FOR I=1 TO 2*KK-1
1380 IF I=20 OR I=0 THEN PNT 'NRML'
1382 IF I=20 OR I=40 THEN PRINT #2,'NORMAL'
1384 PRINT CC(I);
1386 PRINT #2,CC(I);
1388 NEXT I
1390 PRINT 'N'
1392 PRINT #2,'N'
1394 FOR I=1 TO 2*KK-1
1396 IF I=20 OR I=40 THEN PRINT 'REVERSE'
1398 IF I=20 OR I=40 THEN PRINT #2,'REVERSE'
1400 PRINT CR(I);
1402 PRINT #2,CR(I);
1404 NEXT I
1406 PRINT 'R'
1408 PRINT #2,'R'
1409 PRINT #2,
1410 PRINT
1411 PRINT 'COMT1=';TT1;'  COMP2=';TT2
1412 PRINT #2,'COMT1=';TT1;'  COMP2=';TT2
1413 PRINT #2,'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1414 PRINT 'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1415 PRINT 'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1416 PRINT #2,'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1418 T1=T1+T2
1419 T3=T3+T4
1420 T5=T5+T6
1421 T7=T7+T8
1422 IF T1>MIN THEN MIN=T1
1423 IF T3>MIN3 THEN MIN3=T3
1424 IF T7>MIN7 THEN MIN7=T7
1425 IF T5>MIN5 THEN MIN5=T5
1460 DIFF=MIN
1461 DIFF3=MIN3
1465 DIFF5=MIN5
1467 DIFF7=MIN7
1470 IF DIFF<MDIFF THEN MDIFF=DIFF\M=L
1473 IF DIFF3<MDIFF3 THEN MDIFF3=DIFF3\M3=L
1475 IF DIFF5<MDIFF5 THEN MDIFF5=DIFF5\M5=L
1477 IF DIFF7<MDIFF7 THEN MDIFF7=DIFF7\M7=L
1530 PRINT #2,'Prob=';DIFF,'MIN Prob=';MDIFF;'ROT=';M
1531 PRINT 'Prob=';DIFF,'MIN Prob=';MDIFF;'ROT=';M
1533 PRINT #2,'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3
1534 PRINT 'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3
1535 PRINT #2,'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5
1536 PRINT 'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5
1537 PRINT #2,'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7
1538 PRINT 'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7
1540 PRINT
1550 PRINT #2,
1560 NEXT L
1610 NEXT II
1620 PRINT #2,
1680 STOP
```

Apendix B

CROSSCORRELATION SYNC

The following DEC BASIC program was used to calculate the entries in Table 3.

```
SET NO DOUBLE
10 KK=32
20 PRINT 'CROSSCORRELLATION OF SYNC SEQUENCES';KK;'BITS',DATE$(0%)
30 DIM S(9,64),CC(64),CR(64)
40 DECLARE DOUBLE P11(32),P22(32)
50 OPEN 'lp:' FOR OUTPUT AS FILE #2
60 PRINT 'enter 4 probabilities of error'
70 INPUT P,PP,PPP,PPPP
80 PRINT 'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
90 PRINT #2,'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
100 Q=1-P\QQ=1-PP\QQQ=1-PPP
110 QQQQ=1-PPPP
120 LP=LOG10(P)
130 LPP=LOG10(PP)
140 LPPP=LOG10(PPP)
150 LQ=LOG10(Q)
160 LQQ=LOG10(QQ)
170 LQQQ=LOG10(QQQ)
180 L5=LOG10(.5)
190 PRINT #2,'CROSSCORRELLATION OF SYNC SEQUENCES';KK;'BITS',DATE$(0%)
200 LQQQQ=LOG10(QQQQ)
210 LPPPP=LOG10(PPPP)
220 DATA 1,4,2,0,4,1,7,7,7,1,5
230 DATA 1,6,4,6,4,1,0,0,7,7,1
240 DATA 1,4,0,5,5,2,1,6,7,6,2
250 DATA 2,6,3,4,0,6,5,1,0,5,7
260 DATA 2,4,4,0,5,3,5,4,3,7,1
270 DATA 0,6,5,1,3,5,7,4,1,2,3
280 DATA 0,2,4,6,5,4,7,7,4,0,2
290 DATA 0,7,7,2,1,0,2,4,5,6,2
295 DATA 0,3,2,6,3,7,7,6,0,3,5
300 RESTORE 220
310 KK2=KK*2
320 FOR I=1 TO 9
330 PRINT 'SEQUENCE #';I
340 PRINT #2,'SEQUENCE #';I
350 PRINT 'S     ';
360 PRINT #2,'S     ';
370 FOR JJ=0 TO 10
380 READ L
390 IF JJ=6 THEN PRINT #2,
400 FOR J=0 TO 2
410 IF JJ=0 AND J=0 THEN 470
420 K=3*JJ+J
430 EX=2^(2-J)
440 S(I,K)=(L AND EX)/EX
```

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```
450 PRINT S(I,K);
460 PRINT #2,S(I,K);
470 NEXT J
480 PRINT #2,'   ';
490 PRINT '   ';
500 MIN=-100
510 NEXT JJ
520 PRINT
530 PRINT #2,
540 S(I,0)=S(I,K)
550 NEXT I
560 FOR II=1 TO 9
570 MVAR1=100
580 MVAR=100
590 MDIFF1=KK/2
600 MDIFF=KK/2
601 MDIFF3=KK/2
602 MDIFF5=KK/2
603 MDIFF7=KK/2
770 FOR III=1 TO 9
820 PRINT #2,
830 PRINT
840 PRINT '# OF DISAGREEMENTS IN SEQUENCE';II;'AND';III
850 AVE=0\VAR=0\BB=0
860 AVE1=0\VAR1=0\BA=0
870 PRINT #2,'# OF DISAGREEMENTS IN SEQUENCE';II;'AND';III
880 MAX=0
890 MIN=-100
891 MIN3=-100
892 MIN5=-100
893 MIN7=-100
894 T1=0\T2=0
895 T3=0\T4=0
896 T5=0\T6=0
897 T7=0\T8=0
900 PRINT 'S,DEL,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
910 PRINT #2,'S,DEL,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
920 FOR I=1 TO 2*KK-1
930 SS=0
940 SSS=0
945 IF I>KK THEN 982
947 DELTA=I
950 FOR J=1 TO I
960 SS=SS+(S(II,KK-I+J) XOR S(III,J))
970 SSS=SSS+(S(II,KK-I+J) XOR S(III,KK+1-J))
980 NEXT J
981 GOTO 990
982 DELTA=2*KK-I
985 FOR J=I-KK+1 TO KK
986 SS=SS+(S(II,KK-I+J) XOR S(III,J))
987 SSS=SSS+(S(II,KK-I+J) XOR S(III,KK+1-J))
988 NEXT J
990 KISS=DELTA-SS
1000 KISSS=DELTA-SSS
```
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```
1000 KISSS=DELTA-SSS
1001 CR(I)=SSS
1002 CC(I)=SS
1005 DELBAR=KK-DELTA
1010 L5I=L5*DELBAR
1020 P1=LP*SS+LQ*KISS+L5I
1024 IF P1<-10 THEN 1078
1035 P3=LPP*SS+LQQ*KISS+L5I
1037 P5=LPPP*SS+LQQQ*KISS+L5I
1038 P7=LPPPP*SS+LQQQQ*KISS+L5I
1039 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1040 PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1041 IF II=III AND I=KK THEN PRINT \ PRINT #2,\ GOTO 1078
1042 IF SS>1 THEN 1055
1044 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1048 GOTO 1057
1055 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1057 IF P1>-15 THEN P1=F*10^P1 ELSE P1=0
1058 IF P3>-15 THEN P3=F*10^P3 ELSE P3=0
1059 IF P5>-15 THEN P5=F*10^P5 ELSE P5=0
1060 IF P7>-15 THEN P7=F*10^P7 ELSE P7=0
1070 PRINT TAB(30);P1;P3;P5;P7
1071 PRINT #2,TAB(31);P1;P3;P5;P7
1073 T1=T1+P1
1074 T3=T3+P3
1075 T5=T5+P5
1076 T7=T7+P7
1078 REM
1090 P2=LP*SSS+LQ*KISSS+L5I
1100 IF P2<-10 THEN 1180
1105 P4=LPP*SSS+LQQ*KISSS+L5I
1110 P6=LPPP*SSS+LQQQ*KISSS+L5I
1120 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1130 PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1140 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1144 IF SSS>1 THEN 1150
1146 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1148 GOTO 1152
1150 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1152 IF P2>-15 THEN P2=F*10^P2 ELSE P2=0
1154 IF P4>-15 THEN P4=F*10^P4 ELSE P4=0
1156 IF P6>-15 THEN P6=F*10^P6 ELSE P6=0
1158 IF P8>-15 THEN P8=F*10^P8 ELSE P8=0
1160 PRINT TAB(30);P2;P4;P6;P8
1162 PRINT #2,TAB(31);P2;P4;P6;P8
1164 T2=T2+P2
1166 T4=T4+P4
1168 T6=T6+P6
1170 T8=T8+P8
1180 NEXT I
1185 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1186 PRINT #2,'NUMBER OF DISAGREEMENTS(DELT-ALPA)'
1190 FOR I=1 TO 2*KK-1
1191 IF I=20 OR I=40 THEN PRINT 'NORMAL'
1192 IF I=20 OR I=40 THEN PRINT #2, 'NORMAL'
```

```
1194 PRINT #2,CC(I);
1195 NEXT I
1196 PRINT 'N'
1197 PRINT #2,'N'
1198 FOR I=1 TO 2*KK-1
1199 IF I=20 OR I=40 THEN PRINT 'REVERSE'
1200 IF I=20 OR I=40 THEN PRINT #2,'REVERSE'
1201 PRINT CR(I);
1202 PRINT #2,CR(I);
1203 NEXT I
1204 PRINT 'R'
1205 PRINT #2,'R'
1231 PRINT #2,'T1=';T1;'   T3=';T3;'   T5=';T5;'   T7=';T7
1232 PRINT 'T1=';T1;'   T3=';T3;'   T5=';T5;'   T7=';T7
1235 PRINT 'T2=';T2;'   T4=';T4;'   T6=';T6;'   T8=';T8
1236 PRINT #2,'T2=';T2;'   T4=';T4;'   T6=';T6;'   T8=';T8
1249 PRINT 'COMPLEMENTS'
1250 PRINT #2,'COMPLEMENTS'
1255 TT1=0\TT2=0
1256 PRINT 'S,DEL,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
1258 PRINT #2,'S,DEL,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
1260 FOR I=1 TO 2*KK-1
1262 IF I>KK THEN 1268
1264 DELTA=I
1266 GOTO 1270
1268 DELTA=2*KK-I
1270 SS=DELTA-CC(I)
1272 SSS=DELTA-CR(I)
1274 KISS=DELTA-SS
1276 KISSS=DELTA-SSS
1278 CR(I)=SSS
1280 CC(I)=SS
1282 DELBAR=KK-DELTA
1284 L5I=L5*DELBAR
1286 P1=LP*SS+LQ*KISS+L5I
1288 IF P1<-10 THEN 1328
1290 P3=LPP*SS+LQQ*KISS+L5I
1292 P5=LPPP*SS+LQQQ*KISS+L5I
1294 P7=LPPPP*SS+LQQQQ*KISS+L5I
1296 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1298 PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1300 IF SS>1 THEN 1306
1302 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1304 GOTO 1308
1306 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1308 IF P1>-15 THEN P1=F*10^P1 ELSE P1=0
1310 IF P3>-15 THEN P3=F*10^P3 ELSE P3=0
1312 IF P5>-15 THEN P5=F*10^P5 ELSE P5=0
1314 IF P7>-15 THEN P7=F*10^P7 ELSE P7=0
1316 PRINT TAB(30);P1;P3;P5;P7
1318 PRINT #2,TAB(31);P1;P3;P5;P7
1320 T1=T1+P1
1321 TT1=TT1+P1
1322 T3=T3+P3
```

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```
1324 T5=T5+P5
1326 T7=T7+P7
1328 REM
1330 P2=LP*SSS+LQ*KISSS+L5I
1332 IF P2<-10 THEN 1372
1334 P4=LPP*SSS+LQQ*KISSS+L5I
1336 P6=LPPP*SSS+LQQQ*KISSS+L5I
1338 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1340 PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1342 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1344 IF SSS>1 THEN 1350
1346 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1348 GOTO 1352
1350 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1352 IF P2>-15 THEN P2=F*10^P2 ELSE P2=0
1354 IF P4>-15 THEN P4=F*10^P4 ELSE P4=0
1356 IF P6>-15 THEN P6=F*10^P6 ELSE P6=0
1358 IF P8>-15 THEN P8=F*10^P8 ELSE P8=0
1360 PRINT TAB(30);P2;P4;P6;P8
1362 PRINT #2,TAB(31);P2;4P6;P8
1363 T2=T2+P2
1364 TT2=TT2+P2
1366 T4=T4+P4
1368 T6=T6+P6
1370 T8=T8+P8
1372 NEXT I
1374 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1376 PRINT #2,'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1378 FOR I=1 TO K
1380 IF I=20 OR I=40 THEN PRINT 'NORMAL'
1382 IF I=20 OR I=40 THEN PRINT #2,'NORMAL'
1384 PRINT CC(I);
1386 PRINT #2,CC(I);
1388 NEXT I
1390 PRINT 'N'
1392 PRINT #2,'N'
1394 FOR I=1 TO 2*KK-1
1396 IF I=20 OR I=40 THEN PRINT 'REVERSE'
1398 IF I=20 OR I=40 THEN PRINT #2,'REVERSE'
1400 PRINT CR(I);
1402 PRINT #2,CR(I);
1404 NEXT I
1406 PRINT 'R'
1408 PRINT #2,'R'
1409 PRINT #2,
1410 PRINT
1411 PRINT 'COMT1=';TT1;'  COMP2=';TT2
1412 PRINT #2,'COMT1=';TT1;'  COMP2=';TT2
1413 PRINT #2,'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1414 PRINT 'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1415 PRINT 'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1416 PRINT #2,'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1418 T1=T1+T2
1419 T3=T3+T4
```

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```
1420 T5=T5+T6
1421 T7=T7+T8
1422 IF T1>MIN THEN MIN=T1
1423 IF T3>MIN3 THEN MIN3=T3
1424 IF T7>MIN7 THEN MIN7=T7
1425 IF T5>MIN5 THEN MIN5=T5
1460 DIFF=MIN
1461 DIFF3=MIN3
1465 DIFF5=MIN5
1467 DIFF7=MIN7
1470 IF DIFF<MDIFF THEN MDIFF=DIFF\M=II\MM=III
1473 IF DIFF3<MDIFF3 THEN MDIFF3=DIFF3\M3=II\MM3=III
1475 IF DIFF5<MDIFF5 THEN MDIFF5=DIFF5\M5=II\MM5=III
1477 IF DIFF7<MDIFF7 THEN MDIFF7=DIFF7\M7=II\MM7=III
1500 NEXT III
1510 NEXT II
1530 PRINT #2,'Prob=';DIFF,'MIN  Prob=';MDIFF;'ROT=';M;MM
1531 PRINT 'Prob=';DIFF,'MIN  Prob=';MDIFF;'ROT=';M;MM
1533 PRINT #2,'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3;MM3
1534 PRINT 'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3;MM3
1535 PRINT #2,'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5;MM5
1536 PRINT 'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5;MM5
1537 PRINT #2,'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7;MM7
1538 PRINT 'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7;MM7
1540 PRINT
1550 PRINT #2,
1620 PRINT #2,
1680 STOP
```

PERFORMANCE OF CONVOLUTIONALLY CODED SYNCH WORDS

The following program is a calculation of the sync. probabilities for Viterbi-encoded sync. sequences.

```
SET NO DOUBLE
10 KK=52
15 LLL=17
20 PRINT 'CROSSCORR OF CONVOL. ENCODED SYNC SEQUENCES';KK;'BITS',DATE$(0%)
30 DIM S(9,128),CC(128),CR(128)
40 DECLARE DOUBLE P11(32),P22(32)
50 OPEN 'lp:' FOR OUTPUT AS FILE #2
55 PRINT #2,'CROSSCOR OF CONVOL ENCODED SYNC SEQUENCES';KK;'BITS',DATE$(0%)
60 PRINT 'enter 4 probabilities of error'
70 INPUT P,PP,PPP,PPPP
80 PRINT 'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
90 PRINT #2,'length=';KK,'P1=';P,'P2=';PP,'P3=';PPP,'P4=';PPPP
100 Q=1-P\QQ=1-PP\QQQ=1-PPP
110 QQQQ=1-PPPP
120 LP=LOG10(P)
130 LPP=LOG10(PP)
140 LPPP=LOG10(PPP)
150 LQ=LOG10(Q)
160 LQQ=LOG10(QQ)
170 LQQQ=LOG10(QQQ)
180 L5=LOG10(.5)
200 LQQQQ=LOG10(QQQQ)
210 LPPPP=LOG10(PPPP)
220 DATA 1,0,0,7,1,1,3,4,3,2,5,1,6,3,6,4,7,6
230 DATA 1,1,2,1,7,7,2,0,4,0,4,4,1,5,5,0,7,5
240 DATA 1,0,0,7,1,1,3,4,3,2,5,1,6,3,6,4,7,6,2,0,4,2
250 DATA 1,1,2,1,7,7,2,0,4,0,4,4,1,5,5,0,7,5,4,0,7,6
260 DATA 2,3,2,2,0,2,5,6,6,1,7
270 DATA 1,2,2,7,3,7,0,2,4,6,3
280 DATA 3,7,4,0,2,0,5,1,5,3,1
290 DATA 3,1,0,7,7,2,1,0,2,4,5
295 DATA 3,7,7,4,0,7,2,1,5,3,1
300 RESTORE 220
310 KK2=KK*2
320 FOR I=1 TO 4
325 IF I>2 THEN LLL=21
330 PRINT 'SEQUENCE #';I
340 PRINT #2,'SEQUENCE #';I
```

```
350 PRINT 'S      ';
360 PRINT #2,'S      ';
370 FOR JJ=0 TO LLL
380 READ L
390 IF JJ=6 OR JJ=12 OR JJ=18 THEN PRINT #2,
400 FOR J=0 TO 2
410 IF JJ=0 AND J=0 THEN 470
415 IF JJ=0 AND J=1 THEN 470
420 K=3*JJ+J
430 EX=2^(2-J)
440 S(I,K)=(L AND EX)/EX
450 PRINT S(I,K);
460 PRINT #2,S(I,K);
470 NEXT J
480 PRINT #2,'  ';
490 PRINT '  ';
500 MIN=-100
510 NEXT JJ
520 PRINT
530 PRINT #2,
540 S(I,0)=S(I,K)
550 NEXT I
560 FOR II=3 TO 4
565 IF II>2 THEN KK=64
570 MVAR1=100
580 MVAR=100
590 MDIFF1=KK/2
600 MDIFF=KK/2
601 MDIFF3=KK/2
602 MDIFF5=KK/2
603 MDIFF7=KK/2
770 FOR III=II+1 TO 4
820 PRINT #2,
830 PRINT
840 PRINT '# OF DISAGREEMENTS IN SEQUENCE';II;'AND';III
850 AVE=0\VAR=0\BB=0
860 AVE1=0\VAR1=0\BA=0
870 PRINT #2,'# OF DISAGREEMENTS IN SEQUENCE';II;'AND';III
880 MAX=0
890 MIN=-100
891 MIN3=-100
892 MIN5=-100
893 MIN7=-100
894 T1=0\T2=0
895 T3=0\T4=0
896 T5=0\T6=0
897 T7=0\T8=0
900 PRINT 'S,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
910 PRINT #2,'S,dis, p1, p3, p5,p7 for e=0      p1,p3,p5,p7 for e=2'
920 FOR I=1 TO 2*KK-1
930 SS=0
940 SSS=0
945 IF I>KK THEN 982
947 DELTA=I
```

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```
950 FOR J=1 TO I
960 SS=SS+(S(II,KK-I+J) XOR S(III,J))
970 SSS=SSS+(S(II,KK-I+J) XOR S(III,KK+1-J))
980 NEXT J
981 GOTO 990
982 DELTA=2*KK-I
985 FOR J=I-KK+1 TO KK
986 SS=SS+(S(II,KK-I+J) XOR S(III,J))
987 SSS=SSS+(S(II,KK-I+J) XOR S(III,KK+1-J))
988 NEXT J
990 KISS=DELTA-SS
1000 KISSS=DELTA-SSS
1001 CR(I)=SSS
1002 CC(I)=SS
1005 DELBAR=KK-DELTA
1010 L5I=L5*DELBAR
1020 P1=LP*SS+LQ*KISS+L5I
1024 IF P1<-20 THEN 1078
1035 P3=LPP*SS+LQQ*KISS+L5I
1037 P5=LPPP*SS+LQQQ*KISS+L5I
1038 P7=LPPPP*SS+LQQQQ*KISS+L5I
1039 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1040  PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1041 IF I=KK THEN PRINT \ GOTO 1078
1042 IF SS>1 THEN 1055
1044 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1048 GOTO 1057
1055 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1057 IF P1>-20 THEN P1=F*10^P1 ELSE P1=0
1058 IF P3>-20 THEN P3=F*10^P3 ELSE P3=0
1059 IF P5>-20 THEN P5=F*10^P5 ELSE P5=0
1060 IF P7>-20 THEN P7=F*10^P7 ELSE P7=0
1070 PRINT TAB(30);P1;P3;P5;P7
1071 PRINT #2,TAB(31);P1;P3;P5;P7
1073 T1=T1+P1
1074 T3=T3+P3
1075 T5=T5+P5
1076 T7=T7+P7
1078 REM
1090 P2=LP*SSS+LQ*KISSS+L5I
1100 IF P2<-20 THEN 1180
1105 P4=LPP*SSS+LQQ*KISSS+L5I
1110 P6=LPPP*SSS+LQQQ*KISSS+L5I
1120 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1130 PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1140 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1144 IF SSS>1 THEN 1150
1146 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1148 GOTO 1152
1150 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1152 IF P2>-25 THEN P2=F*10^P2 ELSE P2=0
1154 IF P4>-25 THEN P4=F*10^P4 ELSE P4=0
1156 IF P6>-25 THEN P6=F*10^P6 ELSE P6=0
1158 IF P8>-25 THEN P8=F*10^P8 ELSE P8=0
```

```
1160 PRINT TAB(30);P2;P4;P6;P8
1162 PRINT #2,TAB(31);P2;P4;P6;P8
1164 T2=T2+P2
1166 T4=T4+P4
1168 T6=T6+P6
1170 T8=T8+P8
1180 NEXT I
1185 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1186 PRINT #2,'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1190 FOR I=1 TO 2*KK-1
1191 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT 'NORMAL'
1192 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT #2,'NORMAL'
1193 PRINT CC(I);
1194 PRINT #2,CC(I);
1195 NEXT I
1196 PRINT 'N'
1197 PRINT #2,'N'
1198 FOR I=1 TO 2*KK-1
1199 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT 'NORMAL'
1200 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT #2,'NORMAL'
1201 PRINT CR(I);
1202 PRINT #2,CR(I);
1203 NEXT I
1204 PRINT 'R'
1205 PRINT #2,'R'
1231 PRINT #2,'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1232 PRINT 'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1235 PRINT 'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1236 PRINT #2,'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1249 PRINT 'COMPLEMENTS'
1250 PRINT #2,'COMPLEMENTS'
1255 TT1=0\TT2=0
1256 PRINT 'S,DEL,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
1258 PRINT #2,'S,DEL,dis, p1, p3, p5,p7 for e=0        p1,p3,p5,p7 for e=2'
1260 FOR I=1 TO 2*KK-1
1262 IF I>KK THEN 1268
1264 DELTA=I
1266 GOTO 1270
1268 DELTA=2*KK-I
1270 SS=DELTA-CC(I)
1272 SSS=DELTA-CR(I)
1274 KISS=DELTA-SS
1276 KISSS=DELTA-SSS
1278 CR(I)=SSS
1280 CC(I)=SS
1282 DELBAR=KK-DELTA
1284 L5I=L5*DELBAR
1286 P1=LP*SS+LQ*KISS+L5I
1288 IF P1<-20 THEN 1328
1290 P3=LPP*SS+LQQ*KISS+L5I
1292 P5=LPPP*SS+LQQQ*KISS+L5I
1294 P7=LPPPP*SS+LQQQQ*KISS+L5I
1296 PRINT 'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
1298 PRINT #2,'N';I;TAB(6);SS;TAB(9);P1;INT(P3);INT(P5);INT(P7);
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1300 IF SS>1 THEN 1306
1302 IF SS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1304 GOTO 1308
1306 F=SS*(SS-1)*(Q/P)^2/2+SS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1308 IF P1>-20 THEN P1=F*10^P1 ELSE P1=0
1310 IF P3>-20 THEN P3=F*10^P3 ELSE P3=0
1312 IF P5>-20 THEN P5=F*10^P5 ELSE P5=0
1314 IF P7>-20 THEN P7=F*10^P7 ELSE P7=0
1316 PRINT TAB(30);P1;P3;P5;P7
1318   PRINT #2,TAB(31);P1;P3;P5;P7
1320 T1=T1+P1
1321 TT1=TT1+P1
1322 T3=T3+P3
1324 T5=T5+P5
1326 T7=T7+P7
1328 REM
1330 P2=LP*SSS+LQ*KISSS+L5I
1332 IF P2<-20 THEN 1372
1334 P4=LPP*SSS+LQQ*KISSS+L5I
1336 P6=LPPP*SSS+LQQQ*KISSS+L5I
1338 P8=LPPPP*SSS+LQQQQ*KISSS+L5I
1340   PRINT #2,'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1342 PRINT 'R';I;TAB(6);SSS;TAB(9);P2;INT(P4);INT(P6);INT(P8);
1344 IF SSS>1 THEN 1350
1346 IF SSS=0 THEN F=1+2*DELBAR^2 ELSE F=1+2*DELBAR*(Q/P+DELBAR)
1348 GOTO 1352
1350 F=SSS*(SSS-1)*(Q/P)^2/2+SSS*(Q/P)*(1+2*DELBAR)+1+2*DELBAR^2
1352 IF P2>-20 THEN P2=F*10^P2 ELSE P2=0
1354 IF P4>-20 THEN P4=F*10^P4 ELSE P4=0
1356 IF P6>-20 THEN P6=F*10^P6 ELSE P6=0
1358 IF P8>-20 THEN P8=F*10^P8 ELSE P8=0
1360 PRINT TAB(30);P2;P4;P6;P8
1362 PRINT #2,TAB(31);P2;P4;P6;P8
1363 T2=T2+P2
1364 TT2=TT2+P2
1366 T4=T4+P4
1368 T6=T6+P6
1370 T8=T8+P8
1372 NEXT I
1374 PRINT 'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1376 PRINT #2,'NUMBER OF DISAGREEMENTS(DELTA-ALPHA)'
1378 FOR I=1 TO 2*KK-1
1380 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT 'NORMAL'
1382 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT #2,'NOMAL'
1384 PRINT CC(I);
1386 PRINT #2,CC(I);
1388 NEXT I
1390 PRINT 'N'
1392 PRINT #2,'N'
1394 FOR I=1 TO 2*KK-1
1396 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT 'NORMAL'
1398 IF I=20 OR I=40 OR I=60 OR I=80 OR I=100 THEN PRINT #2,'NORMAL'
1400 PRINT CR(I);
1402 PRINT #2,CR(I);
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1404 NEXT I
1406 PRINT 'R'
1408 PRINT #2,'R'
1409 PRINT #2,
1410 PRINT
1411 PRINT 'COMT1=';TT1;'  COMP2=';TT2
1412 PRINT #2,'COMT1=';TT1;'  COMP2=';TT2
1413 PRINT #2,'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';T7
1414 PRINT 'T1=';T1;'  T3=';T3;'  T5=';T5;'  T7=';7
1415 PRINT 'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1416 PRINT #2,'T2=';T2;'  T4=';T4;'  T6=';T6;'  T8=';T8
1418 T1=T1+T2
1419 T3=T3+T4
1420 T5=T5+T6
1421 T7=T7+T8
1422 IF T1>MIN THEN MIN=T1
1423 IF T3>MIN3 THEN MIN3=T3
1424 IF T7>MIN7 THEN MIN7=T7
1425 IF T5>MIN5 THEN MIN5=T5
1460 DIFF=MIN
1461 DIFF3=MIN3
1465 DIFF5=MIN5
1467 DIFF7=MIN7
1470 IF DIFF<MDIFF THEN MDIFF=DIFF\M=L
1473 IF DIFF3<MDIFF3 THEN MDIFF3=DIFF3\M3=L
1475 IF DIFF5<MDIFF5 THEN MDIFF5=DIFF5\M5=L
1477 IF DIFF7<MDIFF7 THEN MDIFF7=DIFF7\M7=L
1500 NEXT III
1530 PRINT #2,'Prob=';DIFF,'MIN Prob=';MDIFF;'ROT=';M
1531 PRINT 'Prob=';DIFF,'MIN Prob=';MDIFF;'ROT=';M
1533 PRINT #2,'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3
1534 PRINT 'Prob=';DIFF3,'MIN3 Prob=';MDIFF3;'ROT=';M3
1535 PRINT #2,'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5
1536 PRINT 'Prob=';DIFF5,'MIN5 Prob=';MDIFF5;'ROT=';M5
1537 PRINT #2,'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7
1538 PRINT 'Prob=';DIFF7,'MIN7 Prob=';MDIFF7;'ROT=';M7
1540 PRINT
1550 PRINT #2,
1610 NEXT II
1620 PRINT #2,
1680 STOP
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